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ADVANCED SIMULATOR FOR PILOT TRAINING: EFFECTS OF COLLIMATION ON ACCOMMODATION AND VERGENCE

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Accommodation and binocular vergence were measured using a haploscope optometer for 10 observers who viewed collimated (0.15 diopter) and noncollimated presentations of a simulated approach and landing. Collimated imagery produced a small but consistent decrease in accommodation for each observer (M = 12.7 meters). Collimation also produced an increase in the perceived size of objects within the visual scene. These results suggest that the primary influence of collimation is on binocular vergence and that differences in the perceived quality of collimated and noncollimated simulator displays are due to differences in binocular vergence rather than in accommodation. Keywords:

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This publication is primarily a working paper.
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SUMMARY

This paper documents in-house research to determine the effects of display collimation on accommodation and binocular vergence. Accommodation and binocular vergence were measured while observers viewed a simulated approach and landing in the Advanced Simulator for Pilot Training. The simulated scene was viewed using either a collimated or a noncollimated display. The results indicated a small but consistent decrease in accommodation when observers viewed the scene through the collimated display and a large decrease in the binocular vergence. Collimation also produced an increase in the perceived size of objects within the simulated scene. These results indicate that consistent physiological and psychological responses are produced by the collimating optics and that these responses are consistent with the subjective feeling of greater depth and volume when viewing collimated displays.

PREFACE

This research was performed in support of the Air Force Human Resources Laboratory's Technical Planning Objective 3, the thrust of which is aircrew training. The general objective of this thrust is the development of cost-effective training strategies and equipment for aircrew training. This work was performed under work unit 1123-32-01, Visual Display System Functional Requirements, monitored by Mr. Robert Woodruff. The goal of this work unit is to determine the training effectiveness of alternative display approaches to visual flight simulation. This work measured the effects of collimating optics on visual accommodation and binocular vergence when observers viewed simulated approaches and landings in the Advanced Simulator for Pilot Training. The results indicate that collimation decreased accommodation and binocular vergence. In addition, collimation increased the apparent size and depth or volume of objects in the visual scene.

The authors express their appreciation to Mr. Mark Maneely for his invaluable assistance in the collection of the data and to the pilots of the 425 Tactical Fighter Training Squadron for their voluntary participation in this experiment.

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ADVANCED SIMULATOR FOR PILOT TRAINING: EFFECTS OF COLLIMATION ON ACCOMMODATION AND VERGENCE

I. INTRODUCTION

This experiment measured accommodation and vergence under viewing conditions representative of those associated with flight simulation. Two approaches are currently used to display the out-of-the-cockpit imagery needed for flight simulation. The first approach presents a virtual image at optical infinity through the use of a collimating lens, while the second approach projects a noncollimated real image onto a display surface located a finite distance in front of the pilot.

One of the reasons frequently cited for employing collimated instead of real-image displays is the effect of collimation on visual accommodation (Kraft & Shaffer, 1978; Snyder, 1982). The collimated image is assumed to produce a low level of visual accommodation similar to that occurring in actual aircraft flight. Collimated images are also assumed to produce accommodation changes when the pilot's fixation shifts between the cockpit instruments and the simulated visual scene.

While it is relatively easy to select a specific display option based on engineering and cost considerations, very few empirical data are available comparing the effectiveness of collimated and noncollimated display approaches. Because of this absence of behavioral data, direct experimental comparisons are needed to determine if significant differences exist in training effectiveness of these two display options (Snyder, 1982).

Such comparisons are of particular interest to the Air Force Human Resources Laboratory (AFHRL) because of its research and development (R&D) programs involving full mission tactical flight simulators. The need to provide a wide field of view approaching that of modern attack and fighter aircraft places unique demands on simulator display systems. For example, the Advanced Simulator for Pilot Training (ASPT), used for training R&D by AFHRL, employs seven collimated display windows to provide a virtual image covering a 300 degree horizontal by 140 degree vertical field of view. Each display window uses the Farrand In-Line Infinity Optical System (ILIOS), or "Pancake Window," which transmits less than 2 percent of the light from the cathode ray tube display to the display surface. The net result of the ILIOS is a simulated visual scene with relatively low luminance and contrast.

One potential solution to the limited luminance and contrast of the ASPT display system is simply to remove the ILIOS, thereby creating a noncollimated rear-projected real image display. This approach offers significant gains in luminance and contrast as well as a reduction in display system costs. However, if the physiological cues of accommodation and vergence are important determinants of pilot performance, such an approach may be counterproductive since the physiological cues presented to the pilot would be characteristic of near rather than distant objects.

Unfortunately, previous perceptual research has provided very few empirical data on which to base a design decision. The perceptual research involving the physiological depth cues of vergence and accommodation suggests that while vergence plays a role in the perception of size and distance, accommodation has very little, if any, influence on these perceptions (Hochberg, 1971; Hokoda & Ciuffreda, 1983; Kaufman, 1974). In addition, it is generally believed that vergence provides size and distance information only within a viewing distance of about 1 meter (Hochberg, 1971; Kaufman, 1974). This suggests that the physiological cues of accommodation and binocular vergence should play relatively minor roles in the final design decision. In addition, the assumption that a pilot routinely accommodates at visual infinity when viewing

out-of-the-cockpit scenes is questionable. A number of studies suggest visual accommodation is biased toward near distances when stimuli are viewed under conditions of low luminance and contrast (Owens & Leibowitz, 1983; Roscoe, 1982).

Prior to this experiment, no data were available describing an observer's accommodation and vergence while viewing ASPT imagery through a ILIOS. Measurements were made while the observer viewed a dynamic computer-generated scene representing the pilot's forward view of an approach and landing at an airfield under both colliminated and noncollimated viewing conditions. The results indicated the collimated ILIOS display produced significantly less accommodation and vergence than did the noncollimated real-image display.

II. METHOD

Observers. Six male pilots and four male nonpilots served as observers in this study. The six pilots were all instructor pilots stationed at Williams Air Force Base and were emmetropes between 27 and 34 years of age with a median age of 30 years. The nonpilots included the two authors, who were myopes with corrections of less than 2 diopters (D), and two additional AFHRL staff members who were emmetropes. The nonpilots ranged in age from 23 to 37 years with a median age of 35 years.

Stimuli. The dynamic playback of a simulated approach and landing in an F-16 was the principal stimulus used in this experiment. This stimulus sequence began approximately 8 km out from the runway and continued until the aircraft stopped on the runway after completing the landing. This sequence was selected because it represented a highly detailed computer-generated scene and therefore provided a number of fixation points. A portion of this scene is shown in Figure 1.

Figure 1. Simulated Scene of Runway for Approach and Landing.

The stimulus sequence was projected using light valve projectors (General Electric Model PJ5155) to produce either a collimated or real image. The collimated image was projected through the ILIOS onto a rear projection screen located 1 meter in front of the subject. The resulting scene collimation was approximately .015 D which corresponds to a viewing distance of 65 meters. The real image was projected directly onto a rear projection screen which was also located one meter in front of the subject. Both scenes provided an instantaneous field of view of 76 degrees with each television line subtending approximately 6 arc minutes of visual angle. The luminance and contrast of the scene shown in Figure 1 were matched for the real and collimated image displays through the use of a Pritchard Photometer (Model 1980A-OP). The minimum scene luminance was 0.34 cd/M^2, the maximum was 2.06 cd/M^2, and the average scene luminance was 1.20 cd/M^2.

Procedure. The purpose of the experiment and the basic aspects of the apparatus were explained to each observer at the beginning of the experiment. The headrest/chinrest assembly of the haploscope optometer was adjusted for each observer, and appropriate corrective lenses were inserted for the myopic observers. Following the alignment of the haploscope optometer, the observer was provided with sufficient practice trials to insure reliable measurements.

Accommodation and vergence were measured statically with a haploscope optometer located at the design eyepoint approximately 1 meter from the display. Accommodation was measured, using the right eye channel, according to the principle of stigmatoscopy (Ciuffreda & Kenyon, 1983). With this method, a small pinhole aperture, or stigma, was imaged into the eye via a Badal lens and a mirror beam splitter (70% transmission). The observer focused on an object in the scene, and adjusted the right arm of the haploscope until the stigma was adjacent to the object. The observer then moved the pinhole aperture along the calibrated right arm of the haploscope until the stigma had the smallest apparent diameter. This produced a measure of the observer's visual accommodation. The vergence measurement was then taken by having the observer rotate the left arm of the haploscope until the left and right stigmas were vertically aligned. The resulting angle of the haploscope arms was then read to obtain a measure of binocular vergence. Observers were frequently reminded to focus on the visual scene and not to fixate on either of the stigmas while making their adjustments.

During actual data collection, five stimulus trials were presented under both the collimated and real-image viewing conditions. All trials under one viewing condition were completed prior to changing conditions, and the ordering of the two viewing conditions was counterbalanced across observers. During each trial, two measurements of accommodation and vergence were obtained. The first measure was obtained by instructing the observer to focus on a ridge located approximately 13 km beyond the aircraft, and the second measurement required the observer to focus on the end of the runway just after the aircraft touched down.

In addition to the accommodation and vergence measures taken as observers viewed the approach and landing, accommodation measures for collimated and real images were also taken while each subject viewed a uniform contourless green raster field having the same average luminance as the airfield scene (1.20 cd/M^2). The range of accommodation, far point to near point, was also measured for each subject.

III. RESULTS

Since a preliminary analysis of the data failed to reveal any consistent differences in accommodation or vergence measures as a function of either the trial number or the object being fixated, the accommodation and vergence readings were averaged over trials and fixation points. Both the accommodation and vergence data were analyzed as split-plot factorials with subject type, pilot or nonpilot, as the between-subject factor and display variables as the

within-subject factors. Because of the unequal number of subjects associated with the two levels of the between-subject factor, a least-squares solution was used in each analysis of variance.

The within-subject factors in the analysis of the accommodation data were the display type (collimated or real), and the type of visual scene (airfield or contourless green raster field). The accommodation results are summarized in Figure 2. A significant main effect was found for the display type ($F = 11.9$; $df = 1,8$; $p < .01$) and for the interaction between display type and scene type ($F = 11.3$; $df = 1,8$; $p < .01$). No other statistically significant main effects or interactions were found for the accommodation data.

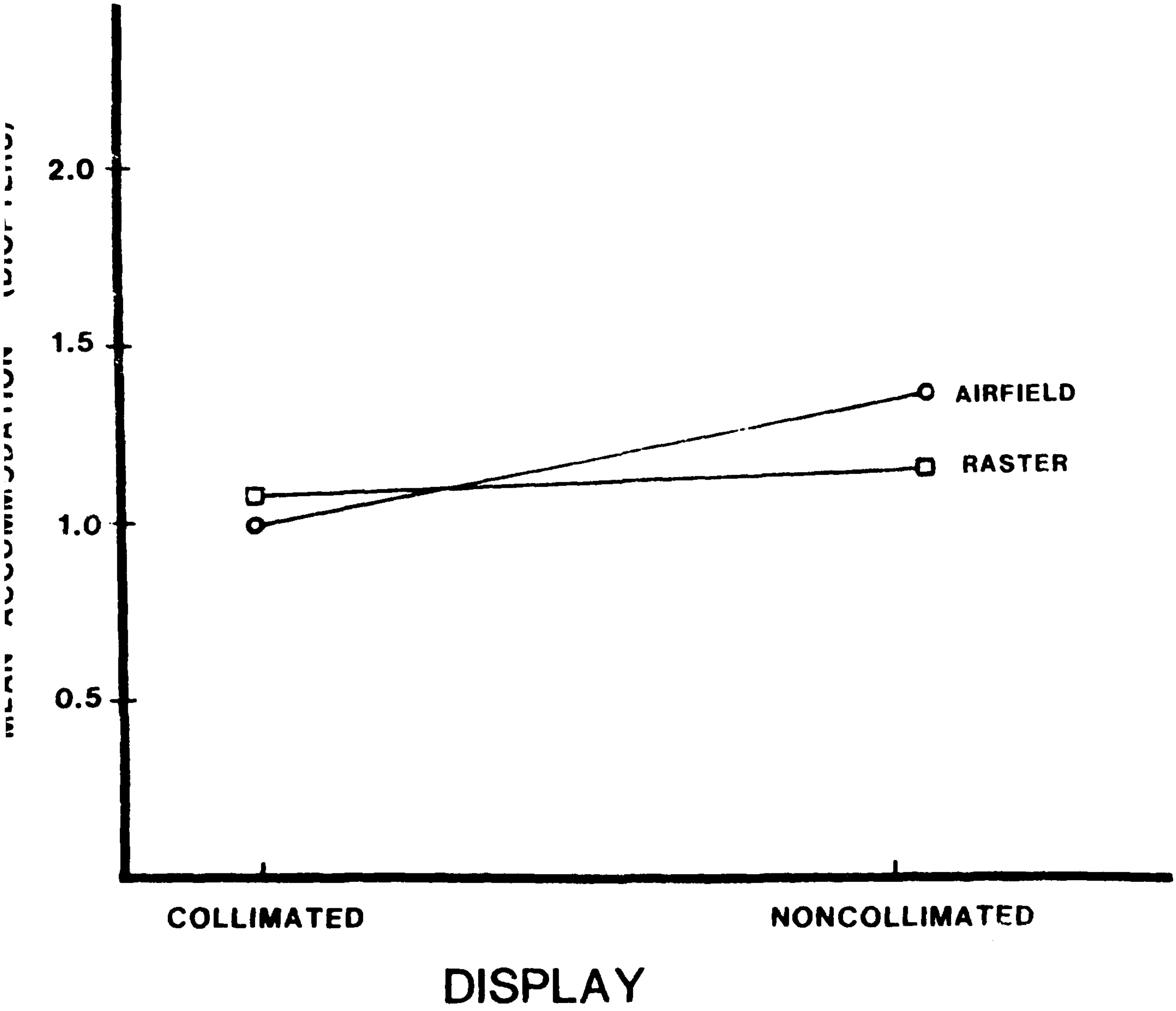

Figure 2. Mean Visual Accommodation as a Function of Display and Scene Type.

Tukey's Honestly Significant Difference (HSD) test (Hays, 1981) was used to describe the interaction between the display and scene types. This test indicated that the real image of the airfield scene produced significantly more accommodation than any of the remaining three combinations of visual scenes and displays ($p < .05$). In addition, no differences between the amount of accommodation produced by the remaining three combinations of visual scenes and display types were found ($p > .05$).

Since all vergence readings were made using the airfield scene, the within-subject factor used in the analysis of the vergence data was the display type (collimated or real). The mean vergence angle for the collimated scene was 0.2 degree, while the corresponding angle for the real image scene was 3.4 degrees ($F = 48.9$, $df = 1,8$; $p < .01$). When corrected for interpupillary separation, these vergence angles corresponded to vergence distances of 13.7 and 1.0 meters, respectively. For pilots, the mean vergence angle was 1.9 degrees; while for nonpilots the mean vergence angle was 1.7 degrees ($F = 2.35$, $df = 1,8$; $p > .10$). The interaction between display type and subject type was nonsignificant ($F < 1.0$).

The mean accommodative range for pilots was 5.3 D; while the corresponding range for nonpilots was 5.0 D ($t = 0.26$; $df = 8$; $p > .10$). The Pearson product moment correlation coefficients for accommodation between the various combinations of display and scene types were all in excess of .90 ($df = 8$; $p < .001$); while the correlation for the vergence angles between the collimated and real images of the airfield scene was -.52 ($df = 8$; $p > .10$).

IV. DISCUSSION

The results of this experiment clearly demonstrate consistent differences in the level of accommodation and binocular vergence produced by collimated and real image displays. All observers showed less accommodation and binocular vergence for the collimated display. These differences are consistent with expectations based on the physical properties of the two display systems. The real-image projection system produced an image on the rear projection screen in such a manner that the light reaching the observer was diverging from an image located approximately 1 meter from the subject. In contrast, the collimated display, although located approximately 1 meter in front of the subject, presented the observer with a pattern of light which was diverging in the same manner as if the scene were located 65 meters from the eyepoint.

These results have important implications for future flight simulator training R&D. Although these results provide no direct evidence related to the training effectiveness of the two display options, they do indicate that accommodation and convergence are in the direction of optical infinity for the ILIOS. Although the accommodation was significantly less for the collimated image, there is very little practical significance associated with the .34 D difference in accommodation obtained between the real and collimated displays. This difference corresponds to only a 24 cm difference in the accommodative distance of the two images and most likely represents the influence of vergence upon the accommodation system (Alpern, 1969).

This finding suggests that with the low-luminance and low contrast imagery representative of flight simulation, vergence rather than accommodation, is the visual response most strongly affected by collimation. The relatively minor change in accommodation is surprising given the traditional emphasis on accommodation in the flight simulation literature (e.g., Snyder, 1982).

An unexpected result in this experiment was a marked difference in the perceived size of objects between the two displays. Six of the 10 observers reported that objects appeared much larger in the collimated displays even though their physical sizes were identical. Observers also reported a greater feeling of depth or volume when viewing the collimated display.

The large vergence difference found in this experiment may be responsible for these perceived differences in the displays since vergence cues have been shown to influence the perception of size and distance (Hochberg, 1971; Hokoda & Ciuffreda, 1983; Kaufman, 1974). However, the reported differences in the apparent size and depth of the image are surprising based on the laboratory data suggesting that vergence is a minor depth and size cue only for relatively close objects (Hochberg, 1971). Further perceptual research in this area should directly examine depth perception and size constancy over a wide range of display conditions.

If binocular vergence, and its associated effect on accommodation, is an important determinant of pilot performance, then the ILIOS would be expected to provide better flight performance in the simulator and also potentially greater training effectiveness, because the ILIOS display more closely approximates the pilot's vergence state for viewing out-of-the-cockpit visual scenes. Future research efforts at AFHRL are planned to examine the effects of real and collimated imagery on specific flight tasks.

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